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# Impact assessment of renewable generation on electricity demand characteristics

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ABSTRACT

In response to variation generation of renewable resources, it is necessary to assess the impacts on electricity demand characteristics. Renewable resources under consideration are photovoltaic, wind, small hydro, biomass, and biogas. It is proposed to treat renewable generation as negative load. Electricity demand is characterized by using peak demand, energy demand, and load factor as well as it is divided into three groups: peak, intermediate, and base. Variation of renewable generation is expressed through a concept of net load. Changes of demand characteristics can be analyzed from annual and seasonal changes of load duration curves after integrating renewable resources. The impacts on demand characteristics and load groups have meaningful implication on operating costs. Numerical results were obtained by using hourly load data and generation portfolio of Thailand.



**Contents**



## 1. Introduction

Development of renewable energy technologies, markets, and investments has been rapid in recent years. Although the world economy has slowed down, the United States, Germany, Spain, China, India, and Brazil continue to lead the world in renewable energy utilization. Renewable energy sources have been utilized to replace fossil-fuelled sources in heating and cooling, transportation, and electricity generation. It is accepted that the growth of renewable energy utilization far exceeds the growth rates of fossil fuels. Technological progress in renewable generation results in cost reduction gradually. Besides, regulatory policies, by means of subsidies and tax exemptions, play important role in driving renewable generation. Renewable power capacity worldwide reached an estimated 1320 GW in 2010 and comprised a quarter of global power capacity from all sources [1].

In rural areas around the globe, renewable energy is increasingly accessible and recognized as sustainable option for off-grid generation. This would have an impact on electricity demand

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forecasting. The forecasted demand of electricity would rather be a net value than a gross value. Besides, major concerns of using renewable resources for electricity generation are the intermittent nature of wind and solar as well as the supply availability of small hydro, biomass, and biogas. The availability of renewable generation may not match with demand variations. For instance, wind availability is high in the early morning while electricity demand is low at the moment. In summer, fuel availability of biomass is low while electricity demand is high.

On supply side, the variable generation of renewable resources could reduce fossil-fuel generation and fuel price fluctuations [2] but would require higher reserve capacity [3] and cycling operation [4]. It is questionable whether operating costs are lower. The answer is definitely dependent on renewable technologies and their penetration level. This subject has been widely studied in the literature [5–13]. On demand side, renewable generation also affects electricity demand characteristics. Because certain renewable resources, such as wind and solar, have intermittent nature so that their generation is not dispatch-able. Renewable generation may technically be considered as negative load [14–16] and its impacts are observed by using the concepts of net load and modified load duration curve [17–19]. When the penetration level of renewable resources is significant, the electricity demand characteristics would be obviously different from the original characteristics. In addition, recent work has also investigated the impacts of vehicle-to-grid and distributed generation in system operation costs and in the power demand curve [20]. By far, the comprehensive work [9] considered the impacts of only wind, photovoltaic, and biomass generation on electricity demand characteristics. The load duration curve was modified on an annual basis. The impact on load groups was only evaluated on particular hours only. The impacts on cycling operation and cost have not been mentioned.

Thus, the objective of this work is to extensively investigate the impacts of renewable generation with a time frame from seasonal basis to annual basis. Renewable resources include photovoltaic, wind, small hydro, biomass, and biogas. Electricity demand characteristics are expressed in terms of peak demand, energy demand, load factor, and load groups. Numerical model is taken from hourly load data and generation data of Thailand during 2009–2011. The main interest is on the changes of peak and energy demands as well as load factor. In addition, the impacts on load and plant groups as well as cycling operation are also subject to investigation in order to fully assess the impact of renewable generation.

## 2. Renewable generation in Thailand

Various renewable resources are available, but those commercially utilized for electricity generation are photovoltaic, wind, small hydro, biomass, and biogas. Renewable resources with limited potential for electricity generation are municipal waste and geothermal power. Photovoltaic and solar thermal capacities have been installed around the world and the investment trend is on the rise given that costs are falling gradually [21]. Wind power has significantly penetrated the renewable energy markets in North America and Europe for a decade and has recently driven its growth by China [1,21]. Hydroelectricity has been widely used for a long time but half of the hydro capacity in the world belongs to the United States, Canada, Brazil, Russia, and China. Typical sizes of hydro capacity are in a wide range (1–1,000,000 kW) but, by tradition, hydro power considered as renewable generation is limited to small-, mini-, micro-, and pico-hydro with capacity up to 10 MW [22]. Biomass is commonly used to produce heat and is transformed to liquid fuel. The use of biomass for electricity generation can be either direct firing or co-firing with fossil fuel. Biogas can be produced from various kinds of biological sources, mostly from animal manure and organic waste. Biogas yields vary widely depending on composition of raw material, in particular, fat content [23,24].

Table 1 shows installed capacities and investments of renewable energy resources in Thailand. Renewable energy utilization in Thailand was dominated by photovoltaic and biomass. Wind power in Thailand is limited, which is opposite to other countries, because wind speed is relatively low. Small hydro power is also limited given that the potential area is only in Northern Thailand. Biogas has been developed to saturation stage. On the other hand, waste power is considered to be at an initial stage. As of 2011, the installed capacity of renewable energy resources is approximately 8% of peak demand in Thailand. However, as shown in Fig. 1, renewable generation is less than 3% of total generation. Renewable generation was low during rainy season (July–October) and high during winter (November–February). Time-of-day energy generation in 2011 is illustrated in Fig. 2. Energy demand in Thailand peaks during 2–4 PM and 7–9 PM. But, renewable generation peaks from 9 AM to 3 PM and almost constant for the rest of the time. The generation behavior of renewable resources is coincident with the operation of production processes which utilizes biomass and biogas generations.

Fig. 3 illustrates the peak demand and renewable capacity of Thailand from 2001 to 2025. By 2015, renewable capacity would be one-third of the forecasted peak demand. But, given the data in Table 1, a realistic projection would have renewable capacity around 15% of the forecasted peak demand. As such, it can be said that renewable generation in Thailand would reach a significant level in a few years.

The generation mixes of Thailand from 2001 to 2025 sorted by fuel type and plant type are shown in Figs. 4 and 5, respectively.

**Table 1**
Installed capacities and investments of renewable energy resources in Thailand during 2009–2011 [25].

| Resource | Installed capacity (MW) | | | Investment (million Baht) | | |
|---|---|---|---|---|---|---|
| | 2009 | 2010 | 2011 | 2009 | 2010 | 2011 |
| PV | 37.0 | 48.6 | 78.7 | 4644 | 32,788 | 24,472 |
| Wind | 5.1 | 5.6 | 7.3 | 954 | 17,465 | 139 |
| Small hydro | 55.7 | 58.9 | 95.7 | 301 | 148 | 330 |
| Biomass | 1618.1 | 1650.2 | 1790.2 | 5349 | 11,846 | 13,901 |
| Biogas | 69.8 | 103.4 | 159.2 | 5275 | 1259 | 3757 |
| Waste | 6.6 | 13.1 | 25.5 | 2169 | 1047 | 2264 |
| Total | 1792.3 | 1879.8 | 2156.6 | 18,692 | 64,553 | 44,863 |

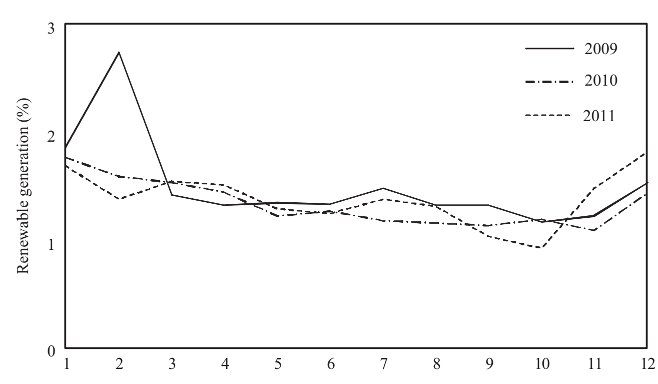


**Fig. 1.** Monthly generation of renewable resources in Thailand during 2009–2011.

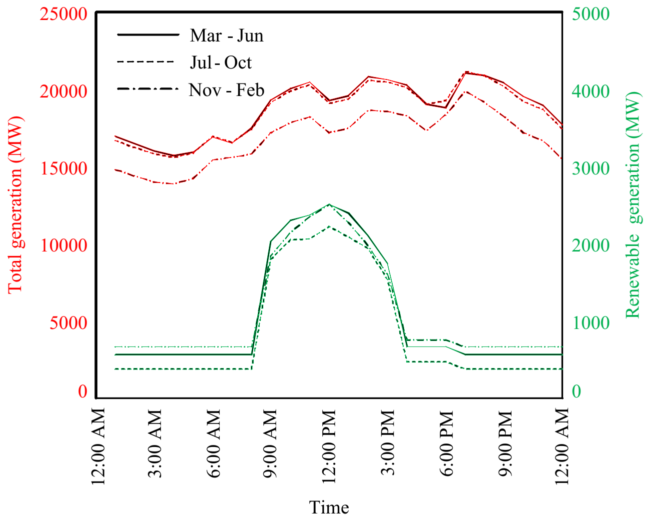


**Fig. 2.** Comparison of hourly generations in Thailand in 2011.

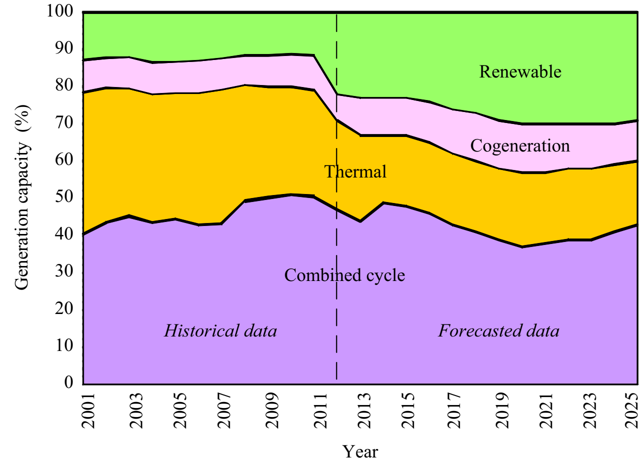


**Fig. 5.** Generation capacity of Thailand sorted by plant type.

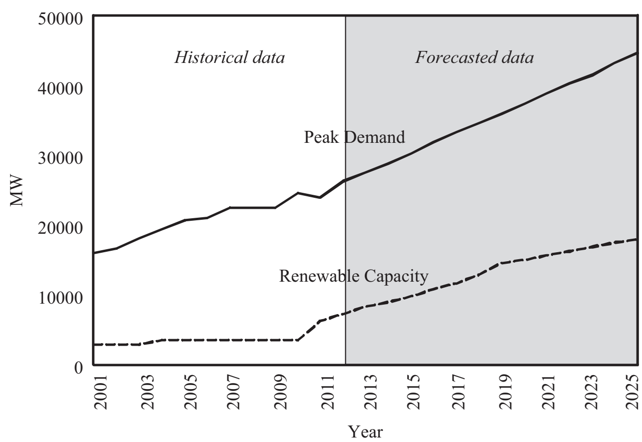


**Fig. 3.** Peak demand and renewable capacity of Thailand.

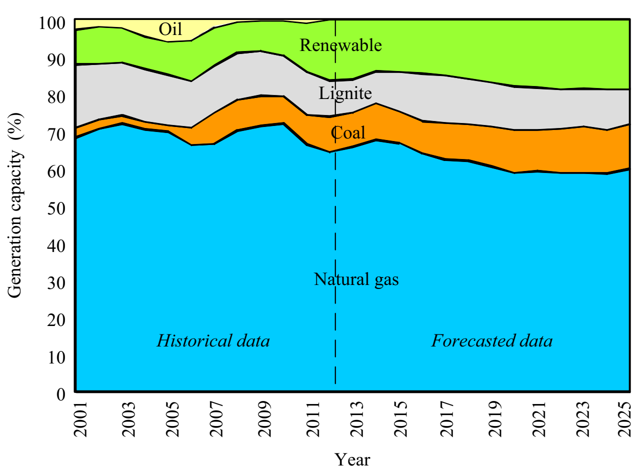


**Fig. 4.** Generation capacity of Thailand sorted by fuel type.

Renewable capacity is projected to be around 15–20% and 20–30% of generation capacity when being sorted by fuel type and plant type, respectively. It is so obvious that the electric supply industry of Thailand depends on natural gas so that supply security and diversity must be critically considered. With a major concern on environmental impact caused by coal and lignite, renewable generation is emerging as a viable alternative for diversifying supply and boosting environmental-friendly generation.

**Table 2**
Annual radiation of solar resource in Thailand [25].

| Region | Annual radiation (MJ/m$^2$/d) |
|---|---|
| North | 17.5 |
| Northeast | 17.9 |
| Central | 18.0 |
| South | 17.6 |

**Table 3**
Annual speed and potential area of wind resource in Thailand [26].

| Wind speed (m/s) | 0–6 | 6–7 | 7–8 | 8–9 |
|---|---|---|---|---|
| Potential area (km$^2$) | 477,157 | 37,337 | 748 | 13 |

## 3. Assessment of renewable generation

### 3.1. Variation generation of renewable resources

The potential resources for electricity generation in Thailand are photovoltaic, wind, small hydro, biomass, and biogas. Their potentials for electricity generation have been assessed by using both literature review and data collection.

It is shown in Table 2 that solar resource in Thailand is considerably abundant throughout the country so that its potential generation is high. In this work, it is assumed that daily period of photovoltaic generation is available between 6 AM and 6 PM and the peak radiation is at 12 noon. On the other hand, wind power generation in Thailand is limited given that the average wind speed is low. Besides, the constant-speed areas are either high-mountain or coastal areas. As shown in Table 3, the average speed in most areas is less than 7 m/s. Thus, wind generation in Thailand is suitable with small wind turbines and available in the nighttime (9 PM–3 AM). Small hydropower generation in Thailand, as shown in Table 4, is mostly on the northern and northeastern regions due to geographical factor. Note that, practically, energy generation from small hydro in the northeastern region is much less than the generation capacity because of limited water.

Biomass resource in Thailand is also abundant but seasonal dependent. It is shown in Table 5 that rice, sugarcane, corn and maize are available 4–8 months, while oil palm and Para rubber are available throughout the year. Biogas generation in Thailand is based on animal waste and waste water from the northeastern and central regions. Estimation of waste resource in Thailand is shown in Table 6. Biogas generation from municipal waste is under development. Biogas generation is assumed to be available 8–16 h/d depending on plant size. Table 7 shows contract capacities of renewable resources. However, some contracts may not proceed to commercial operation. It should be clarified that the contract capacity of wind power is unusually high and subject to further investigation.

Given the contract capacities of all renewable resources in Thailand in 2012, renewable generation can be estimated by summing up all renewable outputs of all resources on an hourly basis. The renewable power output of each resource can be estimated by multiplying its contract capacity with pre-determined conversion efficiency. As shown in Fig. 6, the renewable power output was varied with both time of day and season. The renewable power generation in Thailand was high during daytime (8 AM–4 PM). On a monthly basis, the renewable power generation in Thailand was high in post-harvest months, i.e. November, December, March, and April and was low in pre-harvest months and rainy season, i.e. August and September. It was found that the maximum power output was in April at 12 noon, while the minimum power output was in September at 8 AM. Numerically, it was computed that the maximum and minimum power outputs are 85% and 25% of the total contract capacity, respectively. On average, the power output is 52% of the total contract capacity.

### 3.2. Net load and load duration curve

At a single time instant, net load is defined as electricity demand minus total renewable generation at that time (every half hour or hour). On utility's viewpoint, net load will thus be delivered from electric grid. If the net load value is much lower than the demand (renewable generation is high) during peak-load period, either plant factors or operating durations of peaking plants would decrease substantially. This implies that the operating costs would be lower. But, if the net load value is low during base-load period, change in operating costs would not be substantial given that the operating costs of base plants are much lower than those of peaking plants. Hence, the impact of renewable generation on demand characteristics is time varying and can be visualized by using net load.

Although hourly load curve provides information on time of occurrence and time-varying characteristic, it is not available to determine the relationship between load level and duration corresponding to operating durations of power plants. In power system, load duration curve (LDC) is usually employed to express frequency distribution of the load [29]. LDC is obtained from sorting chronological loads into descending order over a time interval (e.g. 8760 or 8784 h/y). The vertical axis represents load level, while the horizontal axis represents time duration. As a result, it is ready to determine time duration at certain load level. LDC appears to have three regions: the left- and right-ends are steep but the middle is considerably flat. For planning purpose, LDC is typically divided into peak, intermediate, and base loads, on either annual or seasonal basis.

To assess the impact of renewable generation, two LDCs are analyzed: one obtained from hourly load (demand) data and

**Table 4**
Installed capacity of small hydro resource in Thailand [25].

| Region | Installed capacity (MW) |
|---|---|
| North | 42.5 |
| Northeast | 24.2 |
| Central | 12.9 |
| South | 5.2 |
| Total | 84.8 |

**Table 5**
Monthly availability of biomass resource in Thailand [27].

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rice husk | | | | | | | | | | | | |
| Sugarcane | | | | | | | | | | | | |
| Corn & Maize | | | | | | | | | | | | |
| Oil palm & Para rubber | | | | | | | | | | | | |

**Table 6**
Estimation of waste resource in Thailand [25].

| Region | Animal waste (million ton/y) | Waste water (million ton/y) | Municipal waste (million ton/y) |
|---|---|---|---|
| North | 2.7 | 94.8 | 2.8 |
| Northeast | 6.3 | 412.7 | 4.4 |
| Central | 5.3 | 388.2 | 6.8 |
| South | 1.4 | 78.1 | 2.0 |
| Total | 15.7 | 973.8 | 16.0 |

**Table 7**
Contract capacities of renewable resources for electricity generation in Thailand as of 2012 [28].

| Region | Contract capacity (MW) |
|---|---|
| PV | 447.6 |
| Wind | 1506.5 |
| Small hydro | 13.3 |
| Biomass | 1072.8 |
| Waste | 60.0 |
| Total | 3100.2 |

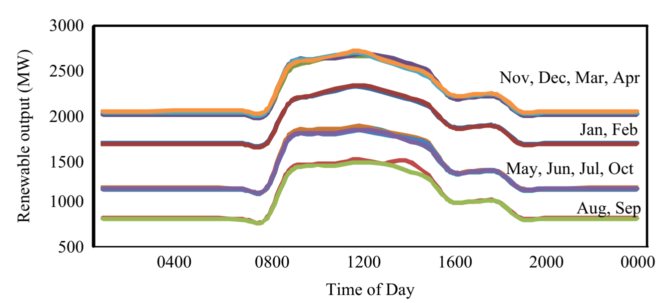


**Fig. 6.** Estimation of renewable power output based on contract capacities of all renewable resources in 2012.

another one obtained from hourly net load data. The shapes of the two LDCs can provide information on whether renewable generation has a correlation with load. The impact can be quantified by considering net load values, peak demand, energy demand, and load factor. The lower the net load value, the higher the renewable generation, and vice versa. The peak demand is obviously the first load level on the left-hand side of the LDC. The energy demand is computed from the area under LDC. By definition, the load factor is the ratio of average load to peak load. If, for instance, the load factor is high, it implies that the LDC is relatively flat and the demand of electricity is relatively constant over time.

## 4. Impact assessment and analysis

### 4.1. Annual impact of renewable generation

The power duration curves of five renewable resources are shown in Fig. 7. On one hand, electricity generation of wind, hydro, and biomass powers is available throughout the year. On the other hand, electricity generation of photovoltaic and biogas powers is available from time to time. The power output of biogas power is constant whenever it is available. When all sources were considered aggregately, it can be estimated that renewable generation is available more than 40% of generation capacity for one-fourth of the time and is available less than 40% of generation capacity for three-fourth of the time. Thus, it may be stated that renewable generation fluctuates from time to time. Numerically, the plant factor of renewable generation is 0.35 which is approximately half of the average plant factor of conventional generation. The plant factor of biomass power is the highest (0.73), while the plant factor of wind power is the lowest (0.08) so that biomass power is relatively steady and wind power highly varies. Comparatively, photovoltaic and biomass highly affect the load duration curve given that their generation capacities are much higher than other resources.

When hourly renewable generation was subtracted from hourly load, it can be seen from Fig. 8(a) that the coincident net load is less than the gross load by 10%. However, the renewable generation at the peak-load hour is higher than other hours so that the peak hour of the net load has shifted from the original hour. The peak hour has shifted from April 24th at 2 PM to April 24th at 4 PM. The minimum load has also shifted from January 1st at 4 AM

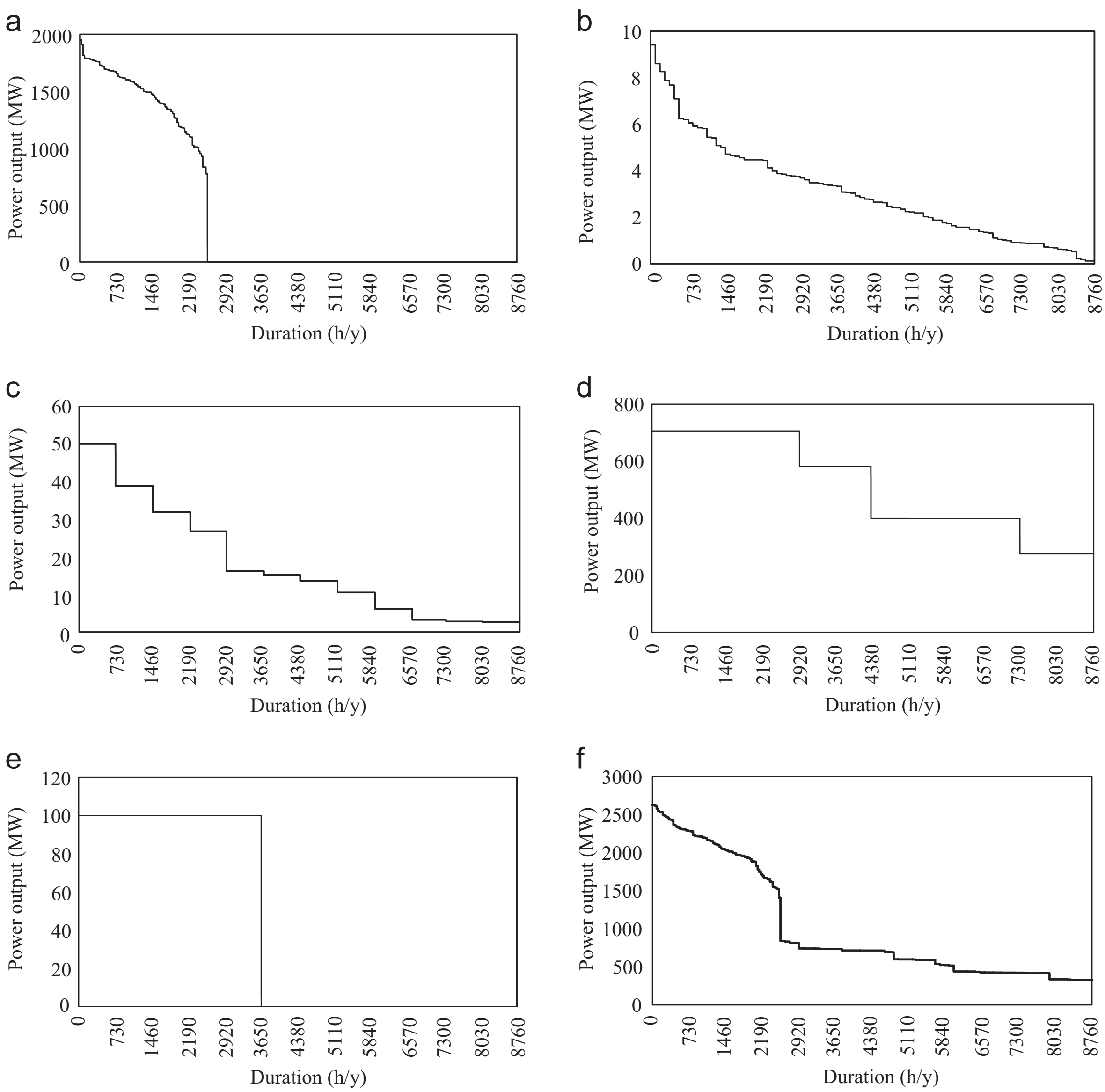


**Fig. 7.** Comparison of annual power duration curves of renewable resources. (a) photovoltaic, (b) wind, (c) small hydro, (d) biomass, (e) biogas and (f) all renewable resources.

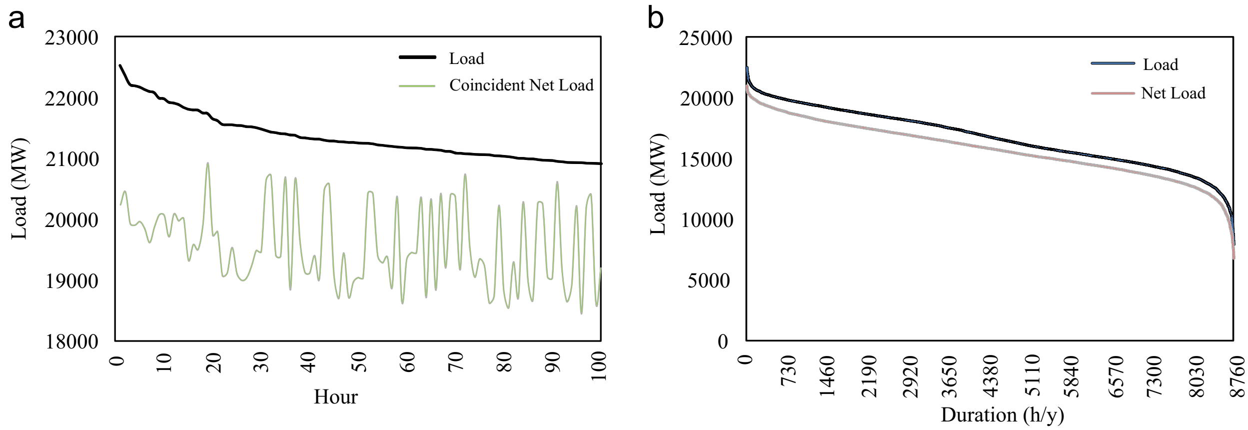


**Fig. 8.** Comparison of annual load duration curve and annual net-load duration curve. (a) top 100 maximum-demand hours and (b) annual curves.

**Table 8**
Comparison of load factors.

| | w/o renewable | w/renewable |
|---|---|---|
| Nov–Feb | 0.76 | 0.73 |
| Mar–Jun | 0.77 | 0.78 |
| Jul–Oct | 0.80 | 0.78 |
| Annual | 0.74 | 0.75 |

to January 1st at 12 noon. As seen from the top 100 maximum-demand hours, it is obvious that conventional power plant is required to vary their generation to cope with fluctuating demand (net load). Variable operation of conventional generation would cause high cycling costs. Fig. 8(b) shows the gross load duration curve and net load duration curve which are similar to each other. As shown in Table 8, it was found that the annual load factor has slightly changed from 0.74 to 0.75. As a result, change in demand characteristics on an annual basis is not substantial.

### 4.2. Seasonal impact of renewable generation

The power duration curves of all renewable resources, except that of biogas, on a seasonal basis are shown in Fig. 9. Based on a seasonal comparison, wind power is relatively low during March–June. Photovoltaic power is relatively constant over all seasons. Hydro power varies by season and is relatively high in the rainy season (July–October). On the contrary, biomass is relatively low during July–October because this period is a cultivation season. As a consequence, renewable generation is relatively low during July–October because biomass has the highest generation proportion. Numerically, maximum renewable output is approximately 91% and 81% of total renewable energy output during November–June and July–October respectively.

Table 9 compares plant (capacity) factors of renewable resources which vary by seasons, except those of biogas. The plant factors of all renewable resources reduce from 0.37–0.38 in November–June to 0.30 in July–October. Variations of plant factors are quite significant, especially the variation of biomass. The variation of small hydro power is the highest but its generation capacity is low so that its impact is not significant. Given variations of plant factors, it is implied that conventional power or energy storage to accommodate unavailability of photovoltaic and wind power is essential. Thus, additional reserve capacity would be required in July–October. Meanwhile, secondary fuel would be a good option for improving biomass power to compete with conventional power.

Fig. 10 shows the gross loads and net loads on a seasonal basis. The net-load duration curves seem to be flatter. By considering only top 100 h of each season, renewable power could reduce electricity demand between 1000 and 3000 MW during November–June, but could reduce electricity demand between 500 and 2000 MW during July–October. Renewable power reduces peak demand in the range of 3–7% in November–June and in the range of 1–2% in July–October. Similarly, renewable power reduces minimum demand by 14–16% during November–June and by 6–7% during July–October. As a result, the gross and net load duration curves during July–October are so close, implying that renewable generation has little impact on demand characteristics during July–October. But it has significant impact on demand characteristics during November–June. In all seasons, renewable generation contributes to base load or low-demand hours more than peak load or high-demand hours. Thus, reduction of generation of base-load power plants could cause excess generation and higher cycling costs, which negatively affect the operating costs. On the other hand, reduction of generation of peak-load power plants positively affects the operating costs.

### 4.3. Impact on load and plant groups

The load was divided into three groups, i.e. peak, intermediate, and base. By applying the K-mean clustering technique [30] to the hourly generation data of Thailand, the base, intermediate, and peak ranges are set as 0–35%, 35–80%, and 80–100% of the peak demand, respectively. When renewable generation is integrated, it can be seen from Table 10 that the penetration level of renewable resources is less than 7% in the intermediate-load and base-load groups and less than 4% in the peak-load group. This can be explained by the photovoltaic and biomass that have small generation in the peak-load period. So, renewable generation has more impact on the base-load and intermediate-load groups than the peak-load group.

The impact of renewable generation on annual energy generation and duration of each load group is shown in Table 11. Both energy generation and duration of the intermediate-load group are constant. While energy generation and duration of the peak-load group are significantly decreasing; consequently, energy generation and duration of the base-load group are increasing. The annual load duration is flatter, resulting in higher (better) load factor. It can then be concluded that renewable generation improves demand characteristics by decreasing the peak-load group and increasing the base-load group. As such, the average operating costs would be lower because the peaking plants have lower generation and the base plants have higher generation.

When considering the impact of renewable generation on a seasonal basis, it is shown in Table 12 that the seasonal impact during November–June is consistent with the annual impact, while the seasonal impact during July–October is different from the annual impact. Note that the seasonal impact is dominated by the generation variations of photovoltaic and biomass given that the generations of other renewable resources were slightly varied with season. Actually, hydro generation was also varied with season but the generation capacity is too small to cause changes. Renewable generation has less impact on the peak-load and base-load groups during July–October, compared with the period of November–February. In other words, the shape of load duration curve during July–October would be slightly changed after integrating renewable generation.

Renewable generation could reduce fossil-fuel generation by 2–4% in the peak-load group, 5–7% in the intermediate-load and base-load groups. Thus, renewable generation contributes to fossil-fuel reduction in the peak-load group less than the intermediate-load and base-load groups. However, the impact on fuel cost is inconclusive unless the fuel mix of each load group is quantified.

Similar to Table 11, the impact of renewable generation on seasonal energy generation and duration of each load group is shown in Table 13. The seasonal impact is also similar to the annual impact. In the period of November–February, renewable generation reduced energy generation and duration in the peak-load and intermediate-load periods by 2–3%. On the contrary, energy generation and duration in the base-load period was increased by approximately 5%. In the period of March–June, renewable generation reduced energy generation and duration in the peak-load period by approximately 6%, while energy generations and durations in the intermediate-load and base-load periods were increased by approximately 3% and 4%, respectively. In the period of July–October, renewable generation reduced energy generation and duration in the peak-load period by 4–5%, while energy generations and durations in the intermediate-load and

**Table 9**
Plant factors of renewable resources on a seasonal basis.

| Resource | Nov–Feb | Mar–Jun | Jul–Oct |
|---|---|---|---|
| PV | 0.13 | 0.15 | 0.14 |
| Wind | 0.10 | 0.04 | 0.08 |
| Small hydro | 0.27 | 0.16 | 0.67 |
| Biomass | 0.92 | 0.79 | 0.48 |
| Biogas | 0.42 | 0.42 | 0.42 |
| All resources | 0.38 | 0.37 | 0.30 |

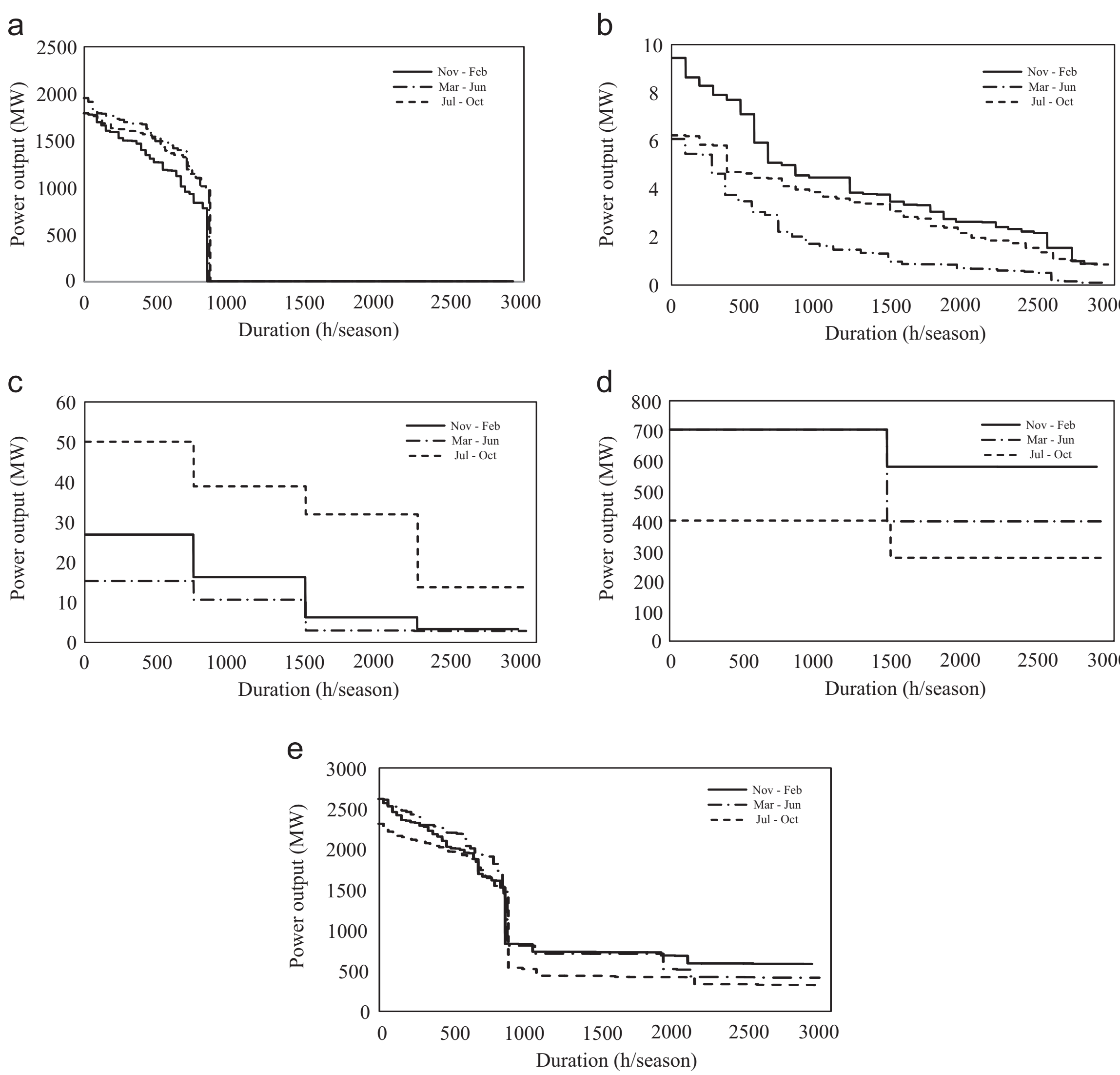


**Fig. 9.** Comparison of seasonal power duration curves of renewable resources. (a) photovoltaic, (b) wind, (c) small hydro, (d) biomass and (e) all renewable resources.

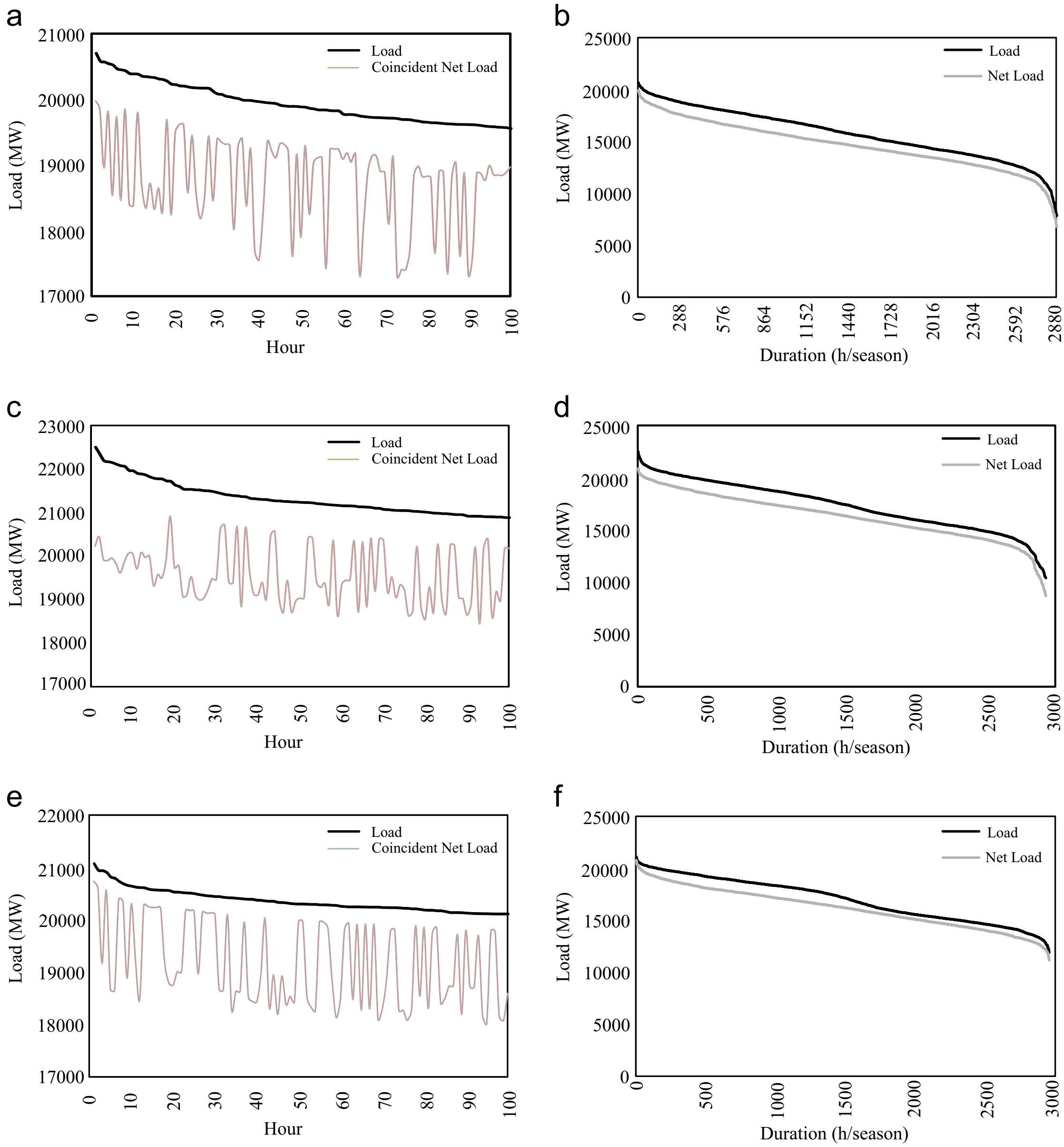


**Fig. 10.** Comparison of seasonal load duration curve and seasonal net-load duration curve. (a) top 100 maximum-demand hours (Nov.-Feb.), (b) seasonal curves (Nov.-Feb.), (c) top 100 maximum-demand hours (Mar.-Jun.), (d) seasonal curves (Mar.-Jun.), (e) top 100 maximum-demand hours (Jul.-Oct.) and (f) seasonal curves (Jul.-Oct.).

**Table 10**
Annual generations sorted by fuel type (unit: %).

| Load group | Fossil | PV | Wind | Small hydro | Biomass | Biogas |
|---|---|---|---|---|---|---|
| Peak | 96.71 | 0.64 | 0.01 | 0.09 | 2.39 | 0.15 |
| Intermediate | 93.88 | 3.00 | 0.02 | 0.11 | 2.69 | 0.31 |
| Base | 93.77 | 2.20 | 0.02 | 0.12 | 3.70 | 0.18 |

**Table 11**
Annual energy and duration of each load group (unit: % per annum).

| Load group | Energy | | Duration | |
|---|---|---|---|---|
| | w/o renewable | w/renewable | w/o renewable | w/renewable |
| Peak | 20.69 | 6.39 | 17.34 | 5.11 |
| Intermediate | 53.64 | 55.81 | 51.84 | 51.32 |
| Base | 25.67 | 37.80 | 30.82 | 43.57 |

base-load periods were increased by approximately 2% and 3%, respectively.

In all seasons, renewable energy reduces energy generation and duration in the peak-load period and increases energy generation and duration in the base-load period. This seasonal impact is consistent with the annual impact mentioned earlier. But, the seasonal impact on the intermediate-load period varies with season. Energy generation and duration are decreased in November–February, but increased in March–October. Hence, it is observed that the impacts of renewable generation in March–June and July–October are consistent with the annual impact, while the impact in November–February is different from the annual impact. This difference may be caused by temperature. Given that the period of November–February has lower average temperature than other months, the intermediate-load group is

**Table 12**
Seasonal generations sorted by fuel type (unit: %).

| Season | Load group | Fossil | PV | Wind | Small hydro | Biomass | Biogas |
|---|---|---|---|---|---|---|---|
| Nov–Feb | Peak | 96.72 | 0.01 | 0.02 | 0.05 | 3.17 | 0.03 |
| | Intermediate | 93.55 | 2.43 | 0.02 | 0.08 | 3.59 | 0.33 |
| | Base | 92.57 | 2.58 | 0.03 | 0.09 | 4.50 | 0.22 |
| Mar–Jun | Peak | 96.04 | 0.99 | 0.01 | 0.04 | 2.75 | 0.18 |
| | Intermediate | 93.64 | 3.06 | 0.01 | 0.04 | 2.96 | 0.28 |
| | Base | 93.84 | 2.12 | 0.01 | 0.05 | 3.80 | 0.17 |
| Jul–Oct | Peak | 98.20 | 0.01 | 0.02 | 0.21 | 1.49 | 0.08 |
| | Intermediate | 94.49 | 3.15 | 0.02 | 0.19 | 1.85 | 0.31 |
| | Base | 95.58 | 1.68 | 0.02 | 0.22 | 2.35 | 0.14 |

**Table 13**
Seasonal energy and duration of each load group (unit: % per annum).

| Season | Load group | Energy | | Duration | |
|---|---|---|---|---|---|
| | | w/o renewable | w/ renewable | w/o renewable | w/ renewable |
| Nov–Feb | Peak | 2.72 | 0.44 | 2.32 | 0.35 |
| | Intermediate | 16.76 | 13.52 | 16.27 | 12.60 |
| | Base | 11.56 | 16.77 | 14.29 | 19.92 |
| Mar–Jun | Peak | 10.96 | 3.91 | 9.10 | 3.12 |
| | Intermediate | 17.83 | 20.80 | 17.29 | 19.01 |
| | Base | 5.94 | 9.98 | 7.03 | 11.30 |
| Jul–Oct | Peak | 7.01 | 2.04 | 5.92 | 1.63 |
| | Intermediate | 19.04 | 21.50 | 18.28 | 19.71 |
| | Base | 8.18 | 11.04 | 9.50 | 12.35 |

larger by means of energy and duration so that renewable generation contributes to lower energy and duration. But, when the average temperature is higher, the intermediate-load group would be smaller and the peak-load group would be larger. In summary, renewable generation has positive impact on the distribution of load groups because the peak-load is decreased and the base-load group is increased so that time-varying characteristic of electricity demand is smaller. In addition, lower operating costs can be expected because peaking plants would have less operation while base plants would have more operation.

Power plants may also be classified into peak, intermediate, and base groups. Peak plants have relatively low capital costs and high operating costs, while base plants have relatively high capital costs but low operating costs. As a result, peak plants have low plant factor and would operate only during peak periods. On the other hand, base plants have high plant factor because they are supposed to operate most of the time at almost full capacity. Peak plants can take a rapid start up or shut down so that cycling operation can be made frequent. Thus, they are promptly responsive to load variation. Intermediate and base plants need longer time to start up and shut down. They are less responsive to changes of load. Base plants are designed to operate continuously and may start up/shut down only a few times a year. Intermediate plants are more flexible for cycling operation than base plants but the number of start-up and shut-down is still limited.

In response to changes of load groups, plant groups are also affected by renewable generation. Given that renewable generation covers peak load slightly but covers intermediate and base loads significantly, it can be said that renewable generation could reduce fuel costs of all plant groups. Nonetheless, the impact on operating is not conclusive, depending on plant groups. The operating costs of peak plants would definitely be lower because they are capable of working cyclically. Reduction of fuel costs would directly force operating costs to be lower. In case of intermediate and peak plants, although renewable generation helps reducing fuel costs but cycling costs may increase. Variable generation of renewable resources causes intermediate and base plants to operate cyclically so that those plants are subject to ageing problem and may require more maintenance. Otherwise, they may be forced to be in spinning mode. Hence, the operating costs of intermediate and base plants would be either lower or higher, depending on plant types. If they are gas-fired power plants, which are more flexible for cycling operation, the operating costs could be lower. But, if they are coal-fired power plants, cycling operation is strictly limited so that the operating costs could be higher. By the way, the impact on revenue is interesting and subject to further investigation. For instance, if gas-fired power plants are more flexible for cycling operation than coal-fired power plants, then gas-fired power plants would have been forced to respond to variable generation. As a result, their revenue would decrease in such scenario.

## 5. Conclusion

It is important to assess the impact of renewable resources on electricity demand characteristics in response to the increasing penetration of renewable generation. Renewable generation was treated as negative load. Change in demand characteristics can be observed by considering change of LDC after integrating renewable resources. LDCs were obtained from hourly load data. It was found that, in case of Thailand, there is significant variation of renewable generation that can be observed from both seasonal and annual timeframes. Renewable generations of photovoltaic and biomass in Thailand highly affect demand characteristics because of their generation capacities which are much higher than other resources. The impact of renewable generation is minimal during July–October given that biomass generation is low during that time period. It was also found that renewable generation affects the shape of LDC and the division of load groups by means of changes of energy generation and duration of each load group. Comparatively, the impact on an annual basis is less obvious than the impact on a seasonal basis.

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